Center Independent Research & Development: JPL IRAD

Tying the Optical and Radio Celestial Reference Frames to Enable Seamless Navigation

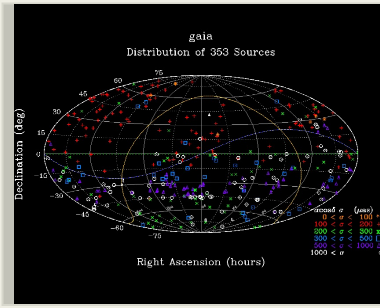
Completed Technology Project (2015 - 2018)

Project Introduction

Navigation requires a references frame. For spacecraft navigation one might colloquially call this a "star map." For the last several decades JPL has navigated interplanetary spacecraft using radio signals. An effort is now under way to navigate using laser signals. This will require "star maps" at visible light wavelengths to complement the existing radio system. Fortunately, the European Space Agency is investing $1 billion to create such maps. Thus, NASA needs only to establish a link to the new system with its existing radio system with the part per billion accuracy needed to avoid degradation of interplanetary navigation. This will allow seamless integration of the new optical maps into the existing, proven system of navigation.

Since the first interplanetary spacecraft, radio frequency communication systems have provided the tracking data necessary to navigate spacecraft to their intended destinations. NASA is now focusing on developing laser communication to allow much higher volumes of scientific data to be transmitted to Earth from deep space. JPL’s first generation optical communications terminal, which may fly on the next selected Discovery mission, has an exclusive focus on communications, as is appropriate for an initial technical demonstration. Looking to the future, utilizing the optical communications infrastructure for navigation as well as data transmission could both save mass and power by not requiring a separate radio frequency navigation system. Optical navigation types would include ranging between spacecraft and the Earth, as well as astrometric measurements of angular position with optical telescopes on both the Earth and spacecraft that will be enabled by the new high precision optical celestial reference frame being created by the ESA Gaia mission. The development of these new optical navigation data types, as well as the required tie between the optical and radio celestial references frames, will also open new opportunities for innovative science investigations, similar to the science benefits reaped from the development of radio navigation techniques. A new R&TD strategic initiative entitled “Navigation and Science in the Optical Era” is designed to position JPL to lead the transition to navigation with optical communications infrastructure and to reap the concomitant science discoveries.

The goal of this task in the initiative is to investigate how to achieve consistent, interchangeable navigation measurements in both optical and radio through aligning reference frames at these two bands together at the sub-nanoradian level. Such an alignment will allow seamless navigation as the optical band is integrated into JPL’s spacecraft navigation architecture. Further, a highly accurate optical reference frame would enable the use of the optical communications infrastructure itself to be used for navigation, analogous to how the radio telecommunications signals can be used for navigation. ESA’s Gaia mission is on course to deliver a sub-nrad optical frame (Mignard et al, 2016). However, this optical frame (while internally rigid due to using quasars with negligible parallax and proper motion) will not be a priori aligned with the JPL radio frame that has been used for decades to navigate



This task has added radio detections of 353 optically bright sources thus more than doubling the number of sources available for a radio-optical frame tie to be used for spacecraft navigation.

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deep space missions. Also, in order to maintain access to radio determined platform calibration parameters (e.g. UT1-UTC and Polar motion), consistent optical and radio frames are required.

The tying of optical and radio frames will be accomplished by observing quasars that are common to both optical and radio frames. A covariance analysis shows that 0.1 nrad precision (1-sigma, per 3-D rotation component) is achievable. We expect that true accuracy will be limited by systematic errors. While the radio error budget is well understood, the Gaia optical frame's systematics are still being determined. Thus our approach will be to obtain radio observations of sources that are optically bright (visual magnitude V < 18) well spread over the sky thus enabling us to probe the Gaia error budget in depth as a function of location on the sky. Further, quasars that are difficult to align may be indicative of underlying astrophysics, such as optical synchrotron jets (Petrov & Kovalev, 2017). If warranted, we will conduct follow-up observations to understand the causes of outliers or discrepant sources.

Anticipated Benefits

Optical systems provide significantly increased data rates or reduced power and a reliable, capable, and cost effective optical communication technology for infusion into operational systems. The present work provides the needed navigation infrastructure to create a compelte optical system for space missions.

This work will allow NASA to leverage the $1 billion investment being made by the ESA to create a highly accurate optical reference frame thus saving NASA from making such a large investment itself.

This technology project will demonstrate and validate a reliable, capable, and cost effective optical navigation technology that can be used for commercial space ventures.

This technology project will demonstrate and validate a reliable, capable, and cost effective optical navigation technology that can be used throughout NASA.

Organizational Responsibility

Responsible Mission Directorate:

Mission Support Directorate (MSD)

Lead Center / Facility:

Jet Propulsion Laboratory (JPL)

Responsible Program:

Center Independent Research & Development: JPL IRAD

Project Management

Program Manager:

Fred Y Hadaegh

Project Manager:

Fred Y Hadaegh

Principal Investigator:

Christopher S Jacobs

Co-Investigator:

Konstantin Belov

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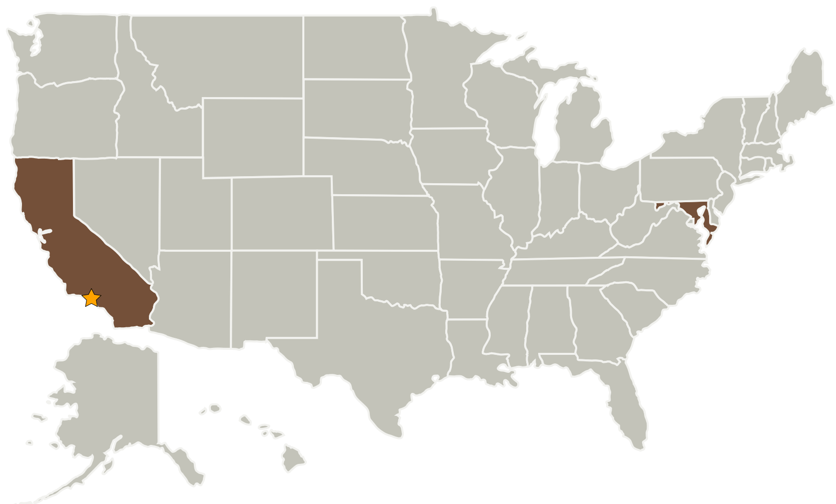
Primary U.S. Work Locations and Key Partners



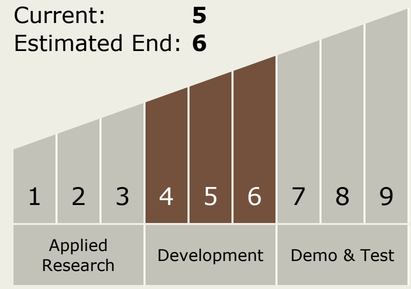
Organizations Performing Work	Role	Type	Location
★Jet Propulsion Laboratory(JPL)	Lead Organization	NASA Center	Pasadena, California

Co-Funding Partners	Type	Location
European Space Agency(ESA)	International	Paris, Outside the United States, France
Hartebeesthoek Radio Astronomy Observatory(HartRAO)	Academia	Hartebeeshoek, Outside the United States, South Africa
Mount Pleasant Radio Observatory	Academia	Cambridge, Outside the United States, Australia

Primary U.S. Work Locations	
California	Maryland

Technology Maturity (TRL)

Start: **4**
Current: **5**
Estimated End: **6**



Technology Areas

Primary:

- TX05 Communications, Navigation, and Orbital Debris Tracking and Characterization Systems
  └ TX05.1 Optical Communications
    └ TX05.1.6 Optimetrics

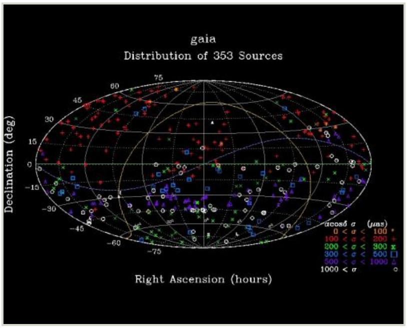
Target Destination

Others Inside the Solar System

Supported Mission Type

Push

Images



Project Image
This task has added radio detections of 353 optically bright sources thus more than doubling the number of sources available for a radio-optical frame tie to be used for spacecraft navigation.
(https://techport.nasa.gov/image/28037)